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Investigation on the Influence of Survey Method to Prioritizing Safety Culture Attributes using AHP Method

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1. Introduction

Safety culture measurement is an indicator set to examine the level, characteristics, or state of safety culture in an organization. Through this, the soundness of an organization's safety culture is identified and, if there is a weakness, it can be improved before a problem occurs. Therefore, it is necessary to evaluate the safety culture measurement results conducted targeting nuclear power plants (power plant workers) to identify the difference in perception of safety culture among workers at nuclear power plants. Nevertheless, current survey approach/method such as a constant sum scale questions for measuring attributes of the safety culture has strongly depend on surveyee’s nature because this type of question uses in a survey in which respondents are required to divide a specific number of points as part of a total sum. Therefore, this approach is not able to understand individual preferences and identify relative rankings based on relative attractiveness.

Hence, the Analytic Hierarchy Process (AHP) method can be usefully to obtain the importance (weight) of survey factors/questionnaires where surveyees are asked to select their preferred option from survey factors/questionnaires. It helps identify the most preferred factors/questionnaires among a set of survey factors/questionnaires and provides insights into individual preferences and choices. For instance, if surveyee has to choose two factors/questionnaires between two attributes of safety culture, the manager’s safety responsibility and the worker’s safety responsibility, however both of them may not have equal importance in surveyee’s perception. In case that the manager’s safety responsibility may be more important than the worker’s safety responsibility, the surveyee assign high weightage to the manager’s safety responsibility and low weightage to the worker’s safety responsibility. Nevertheless, weightages of them have applied equal importance in the current survey method. Hence, a graded comparative judgment about the pair in terms of the relative importance of attributes is needed to reach logically consistent solutions with respect to the goal (good safety culture). The comparative judgement is taken on a semantic scale (equally important / moderately more important / strongly important and so on) and is converted into a numerical integer value.

In this regard, this study adopted the AHP approach to reevaluate aimed for identifying individual surveyee’s preferences and rank items based on relative attractiveness in a discriminatory manner. In order to identify an influence of the safety culture survey approach on preferences and prioritizing safety culture attributes, an evaluation to the self-survey measurements performed in years 2014 and 2015 respectively by Korea Hydraulic and Nuclear Power company (KHNP) conducted using the AHP approach.

2. Methods and Results

Since the influence of safety culture attributes is depending on the survey method and surveyee’s nature, the safety perception identified from the survey results was re-evaluated with an aim for the verification of their adequacy using the AHP method. This method is employed for ranking a set of alternatives (attributes) in the survey results or for the selection of the best in a set of alternatives (attributes) in the survey results.

2.1 AHP Method

The AHP method is a technique for selecting the optimal alternative by identifying the importance of each attribute by classifying a number of attributes hierarchically. The implementation procedure consists of the structuring step of the comparison target, the pairwise comparison step, and the weight derivation step.

(1) Establishing a hierarchical structure

The AHP hierarchy has Goal (purpose) at the top, Criteria (goal) below it, and Alternatives (alternatives) at the bottom layer as shown in Figure 1. If it is necessary to divide the element that is the criterion for judgment into several stages, a sub-criterion is placed under the Criteria, and furthermore sub-criterion can be placed.

In this step, the objects for which importance (weight) is to be derived are expressed in several layers or in the form of a network. In order to maintain a robust safety culture, the ranking of important safety culture attributes was derived.

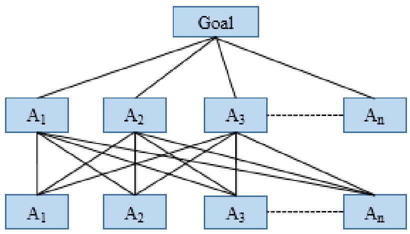

Figure 1 Example of a tiered model

(2) Setting relative importance

In a complex decision-making situation, the weight or importance of numerous decision-making factors/questionnaires is composed of a comparison matrix of all data for each factor through pairwise comparison (1:1 comparison) for each factor.

In this study, two pairs of evaluation factors/questionnaires expressed as lower goals or evaluation criteria included in each layer are paired and pairwise compared based on the goal of the upper layer. 9-point scale has been applied experimentally as shown in Table 1. A pairwise comparison was performed for each survey element using the 9-point scale.

Table 1 Example of pairwise comparison

scale	1	2	3	4	5	6	7	8	9	scale
	A is much more important than B	A is much more important than B	A is more important than B	A is slightly more important than B	A is equally important as B	B is slightly more important than A	B is more important than A	B is much more important than A	B is much more important than A	
A	0.88-0.91	0.92-0.94	0.94-0.96	0.97-0.99	1.00	1.01-1.02	1.03-1.04	1.05-1.06	1.07-1.08	B
A_1										B_1
A_2										B_2
…										…
A_n										B_n

(3) Maintenance of logical consistency

AHP derives the "consistency index" in the process of integrating the 1:1 comparison results using the eigenvectors of the comparison matrix to check whether the decision maker maintains logical consistency and to check the rationality and logic of decision making. The consistency ratio shows how much the consistency of the respondent responding to the survey differs from the consistency of random responses. The consistency index, CI, is defined as follows.

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1}$$

$$\lambda_{max} \geq n$$

The random indices obtained from the inverse matrix randomly calculated from the scale. The size of the matrix for the random index, RI is as shown in Table 2.

Table 2 Random Consistency Index by Matrix Size

Matrix size	Random consistency index	Matrix size	Random consistency index	Matrix size	Random consistency index
1	0	6	1.25	11	1.52
2	0	7	1.35	12	1.54
3	0.52	8	1.40	13	1.56
4	0.89	9	1.45	14	1.58
5	1.11	10	1.49	15	1.59

Therefore, a consistency ratio (CR) can be obtained by dividing the consistency index by the random index.

$$\mathrm{CR} = \frac{CI}{RI}$$

Respondents are not expected to respond perfectly in pairwise comparisons, but usually a CR of 10% (0.1) or less is considered good. When subjective pairwise comparison is arbitrarily performed, a value of CR may occur to exceed 0.1, it is judged to be losing logical consistency, and the process should be reexamined.

2.2 Assessment of influence on safety culture attributes

(1) Influence analysis

In this step, the data answered by the expert group are arranged in a square matrix, and the importance (weight) for each problem is calculated using this matrix. Assuming $a_1 \ldots a_n$ as measured values for items $a_1 \ldots a_n$, if the pairwise comparison values for each evaluation element are arranged in a square matrix [A], it is as follows.

Table 3 Square matrices of pairwise comparison values

Survey items	A_1	A_2	…	A_n
A_1	a_{11}	a_{12}	…	a_{1n}
A_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
A_n	a_{n1}	a_{n2}	…	a_{nn}

$$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

The elements of matrix, or ratio between compared criteria are expressed by the formula:

$$a_{i,j} = \frac{w_i}{w_j}$$

Normalized matrix B = [b_{ij}]

$$b_{i,j} = \frac{\alpha_{ij}}{\sum_1^n \alpha_{ij}}$$

The calculation of the weights i.e. eigenvector w= [w_i] form the normalized matrix B is performed by calculating the arithmetic mean for each row of the matrix according to the formula:

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n}$$

In Table 3, V_1 compares A_1 itself to A_1 itself, and its value is 1. is the value representing the importance of A_1 compared to A_2, and V_1/V_2 is the pairwise comparison value of A_1 compared to A_n. There are arithmetic average and geometric average to obtain the weight for each problem using the paired comparison value. As an arithmetic average, the weight of each problem $W_1 \ldots W_n$ is obtained as follows.

$$W_1 = (\frac{V_1}{V_1} + \frac{V_1}{V_2} + \cdots + \frac{V_1}{V_n})/n$$

$$W_2 = (\frac{V_2}{V_1} + \frac{V_2}{V_2} + \cdots + \frac{V_2}{V_n})/n$$

$$\cdots$$

$$W_n = (\frac{V_n}{V_1} + \frac{V_n}{V_2} + \cdots + \frac{V_n}{V_n})/n$$

Here, is the sum of the pairwise comparison values in column 1, and the sum of standardized weights is 1. Each weight is the average of the total number of environmental problems (n) by summing the values obtained by dividing the pairwise comparison values of each row in the square matrix [A] by the sum of pairwise comparisons of the corresponding column.

(2) Consistency analysis

In this step, it is checked whether the data answered by the expert group are reliable and consistent. To this end, congruency analysis is performed to find out how consistently the expert group responded.

In the consistency analysis procedure, first, λ_{max} is derived: when n × n square matrix [A] is multiplied by n × n weight matrix [W], a new n × n weight vector matrix [Y] is calculated. λ_{max} can be obtained using $Y_1 \ldots Y_n$ and weight $W_1 \ldots W_n$. Expressing this as a formula is:

$$[A] \times [W] = [Y]$$

$$\max_{1 \le i \le n} [A_i] = \max_{1 \le i \le n} \frac{[Y_i]}{[W_i]} = \lambda_{max}$$

λ_{max} is the largest eigenvalue of the matrix A.

Next, a consistency analysis is needed to find out how consistently the seriousness of the elements judged subjectively by the expert group satisfies the axiom of transitivity and responded consistently.

To perform a consistency analysis, first, the maximum eigenvalue λ_{max} must be obtained, and secondly, the Consistency Index (CI) must be obtained using λ_{max}.

Third, the CR is obtained. Consistency is determined using this CR. Then, the consistency check is determined by the CR, which means the weight between the CI and the R) determined for each matrix size.

2.3 Results of influence evaluation

For the survey measurement results to surveyees in 6 nuclear power plants (more than 2,000 workers including supporting contractors) performed by nuclear operating organization in 2014 and 2015 respectively as shown in Table 5, the importance (weight) of safety culture attributes and the appropriateness of the 8 safety culture attributes are evaluated as shown in Table 4.

The importance (weight) evaluation is shown in a matrix as shown in Tables 7 and 8 for the evaluation factors/questionnaires for pairwise comparison, and the weight was derived by calculating the square matrix as shown in Table 6. As shown in Tables 9 and 10, the results of the pairwise comparison were converted into a matrix and the weights were derived with the AHP program.

Table 4 Safety culture attributes

Metric items		Evaluation traits contents
1	Worker's safety responsibility	Compliance with procedures and regulations, fulfillment of duties assigned
2	Manager's Safety Responsibility	Safety management, manager observation and coaching
3	Creating a safety-oriented environment	Corrective action program (CAP)/ Employee concerns program (ECP), safety culture review body operation
4	Conservative decision making	Principles of plant nuclear safety committee (PNSC) convening meetings, revitalization of objection system
5	Risk work management	Risk management using risk informed management system (RIMS), test and work plan reflection
6	Questioning attitude	Suspension of work in case of doubt and compliance with pre-job briefing (PJB) issued by CAP / utilization of safety task action reporting (STAR) human error prevention technique during work
7	Creating learning atmosphere	Utilization of domestic and foreign driving experience (OE), establishment of test/work plan and review of OE at PJB
8	Continuous safety diagnosis	Safety culture self-diagnosis, practice indicator monitoring, trend analysis and improvement

Table 5 Safety culture measurement results by year

Index / year	1	2	3	4	5	6	7	8	Average
year 2015	84,1	88.6	86.5	86.5	84.7	86.3	82.1	80.9	85.0
year 2014	88.3	86.9	83.3	77.8	85.0	82.5	80.3	83.4	83.1
year 2013	90.8	86.6	*	83.1	*	88.7	83.0	77.5	84.9
Year 2012	76.7	85.0	*	69.5	*	86.4	78.2	81.8	77.9

*: Since 2014, the safety culture evaluation index has been changed from 6 to 8 and applied extensively.

Table 6 Square matrices of pairwise comparison values

Survey items	A_1	A_2	…	A_n
A_1	V_1/V_1	V_1/V_2	…	V_1/V_n
A_2	V_2/V_1	V_2/V_2	…	V_2/V_n
…	…	…	…	…
A_n	V_n/V_1	V_n/V_2	…	V_n/V_n

Table 7 Pairwise comparison normalization for 2014 case

Attributes	1	2	3	4	5	6	7	8
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
Measured	88.3	86.9	83.3	77.8	85	82.5	80.3	83.4
$V_{1\ldots} V_8/V_1$	1.00	0.98	0.94	0.88	0.96	0.93	0.91	0.94
$V_{2\ldots} V_8/V_2$		1.00	0.96	0.90	0.98	0.95	0.92	0.96
$V_{3\ldots} V_8/V_3$			1.00	0.93	1.02	0.99	0.96	1.00
$V_{4\ldots} V_8/V_4$				1.00	1.09	1.06	1.03	1.07
$V_{5\ldots} V_8/V_5$					1.00	0.97	0.94	0.98
$V_{6\ldots} V_8/V_6$						1.00	0.97	1.01
$V_{7\ldots} V_8/V_7$							1.00	1.04

Table 8 Pairwise comparison normalization for 2015 case

Attributes	1	2	3	4	5	6	7	8
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
Measured	84.1	88.6	86.5	86.5	84.7	86.3	82.1	80.9
V_1... V_8/V_1	1.00	1.05	1.03	1.03	1.01	1.03	0.98	0.96
V_2... V_8/V_2		1.00	0.98	0.98	0.96	0.97	0.93	0.91
V_3... V_8/V_3			1.00	1.00	0.98	1.00	0.95	0.94
V_4... V_8/V_4				1.00	0.98	1.00	0.95	0.94
V_5... V_8/V_5					1.00	1.02	0.97	0.96
V_6... V_8/V_6						1.00	0.95	0.94
V_6... V_8/V_7							1.00	0.99

Table 9 AHP evaluation matrix for 2014 case

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1	1.000	0.200	1.000	1.000	5.000	1.000	3.000	5.000
V_2	5.000	1.000	3.000	3.000	5.000	3.000	7.000	9.000
V_3	1.000	0.333	1.000	1.000	3.000	1.000	5.000	7.000
V_4	1.000	0.333	1.000	1.000	3.000	1.000	5.000	7.000
V_5	0.200	0.200	0.333	0.333	1.000	0.333	3.000	5.000
V_6	1.000	0.333	1.000	1.000	3.000	1.000	7.000	3.000
V_7	0.333	0.143	0.200	0.200	0.333	0.143	1.000	3.000
V_8	0.200	0.111	0.143	0.143	0.200	0.333	0.333	1.000

Table 10 AHP evaluation matrix for 2015 case

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1	1.000	3.000	7.000	9.000	5.000	7.000	9.000	5.000
V_2	0.333	1.000	5.000	9.000	3.000	5.000	7.000	5.000
V_3	0.143	0.200	1.000	7.000	0.333	3.000	5.000	1.000
V_4	0.111	0.111	0.143	1.000	0.111	0.143	0.200	0.111
V_5	0.200	0.333	3.000	9.000	1.000	3.000	7.000	3.000
V_6	0.143	0.200	0.333	7.000	0.333	1.000	3.000	0.333
V_7	0.111	0.143	0.200	5.000	0.143	0.333	1.000	0.200
V_8	0.200	0.200	1.000	9.000	0.333	3.000	5.000	1.000

(1) Evaluation for 2014 measurement case

The weight evaluation result for each safety culture attributes in 2014 shows that the priority (ranking) for safety culture awareness is identified on the order of: "Manager's safety responsibility (V_2)", "Questioning attitude (V_6)", "Worker's safety responsibility (V_1)", "Creating a safety oriented environment (V_3)", "Conservative decision making (V_4)", "Risk work management (V_5)", "Creating a learning atmosphere (V_7)", and "Continuous safety diagnosis (V_8)".

Meanwhile the priority (ranking) for survey results appeared on the order of: "Worker's safety responsibility (V_1)", "Manager's safety responsibility (V_2)", "Risk work management (V_5)", "Continuous safety diagnosis (V_8)", "Creating a safety oriented environment (V_3)", "Questioning attitude (V_6)", "Creating a learning atmosphere (V_7)" and "Conservative decision making (V_4)".

Table 11 shows the difference between survey results and reexamination result using AHP because it may cause by either taking in account of weightage of surveyee's perception to the survey indicators (attributes) or not. In case of the survey results, all survey indicators (attributes) were taken as an equal importance while reexamination results were included weightage of each attributes during the comparative judgement by the AHP method.

The evaluation results for the 8 safety culture principles were shown in the radar chart as shown in Figure 2.

Table 11 Results of safety culture awareness in 2014

Attributes		Sum of rows in matrix	Normalization (Eigen Vector)	Ranking	Survey Ranking
V_1	Worker's safety responsibility	160.775	0.140	3	1
V_2	Manager's safety responsibility	401.638	0.349	1	2
V_3	Creating a safety-oriented environment	160.406	0.140	4	5
V_4	Conservative decision making	160.406	0.140	4	8
V_5	Risk work management	68.081	0.059	6	3
V_6	Questioning attitude	161.257	0.140	2	6
V_7	Creating a Learning Atmosphere	37.295	0.032	7	7
V_8	Continuous safety diagnosis	25.069	0.022	8	4
Sum		1149.859	1.000		

Figure 2 Evaluation result for 2014 case

As for the reliability (consistency) verification of the measurement results, as shown in Table 12, the Consistency Ratio (CR) was 0.053, which was less than the standard value of 10% (0.1), and the data answered by the safety culture evaluator group were evaluated as being consistent.

Table 12 Results of AHP importance evaluation

Metrics	Pairwise Comparison Matrix X Eigen Vector(①)	①/Eigen Vector
V1	1.131	8.0906
V2	3.025	8.6599
V3	1.168	8.3701
V4	1.168	8.3701
V5	0.503	8.4958
V6	1.145	8.1686
V7	0.290	8.9464
V8	0.198	9.0735
λ_{max} -n		0.5219
CI		0.0746
RI		1.4000
CR		$0.0530 \leq 0.1$
Consistency		Yes

(2) Evaluation for 2015 measurement case

The weight evaluation result for each safety culture attributes in 2015 shows that the priority (ranking) for safety culture awareness is identified on the order of: "Worker's safety responsibility (V_1)", "Manager's safety responsibility (V_2)", "Risk work management (V_5)", "Continuous safety diagnosis (V_8)", "Creating a safety oriented environment (V_3)", "Questioning attitude (V_6)", "Creating a learning atmosphere (V_7)" and "Conservative decision making (V_4)".

In case of the survey results, the priority (ranking) appeared on the order of: "Manager's safety responsibility (V_2)", "Creating a safety oriented environment (V_3)", "Conservative decision making (V_4)", "Worker's safety responsibility (V_1)," "Creating a learning atmosphere (V_7)" and "Continuous safety diagnosis (V_8)".

Table 13 also shows the difference between survey results and reexamination result using AHP due to different approaches with taking weightage of surveyee's perception to the survey indicators (attributes) or not.

Table 13 Results of safety culture awareness in 2015

Attributes		Sum of rows in matrix	Normalization (Eigen Vector)	Ranking	Survey Ranking
V_1	Worker's safety responsibility	675.010	0.402	1	6
V_2	Manager's safety responsibility	446.311	0.266	2	1
V_3	Creating a safety-oriented environment	146.083	0.087	5	2
V_4	Conservative decision making	21.822	0.013	8	2
V_5	Risk work management	264.051	0.157	3	5
V_6	Questioning attitude	82.197	0.049	6	4
V_7	Creating a Learning Atmosphere	42.326	0.025	7	7
V_8	Continuous safety diagnosis	152.571	0.091	4	8
Sum		1677.800	1.000		

The evaluation results for the 8 safety culture attributes were shown in the radar chart as shown in Figure 3.

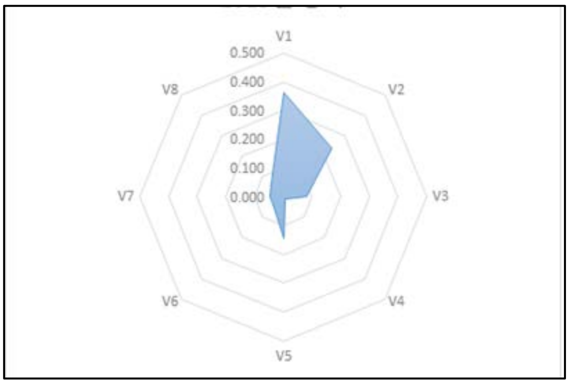

Figure 3 Evaluation result for 2015 case

As for the reliability (consistency) verification of the measurement results, as shown in Table 14, the consistency ratio (CR) is 0.103, which is slightly above the standard value of 10% (0.1). Nevertheless, the data showed are relatively consistent.

Table 14 Results of AHP importance evaluation

Metrics	Pairwise Comparison Matrix X Eigen Vector(①)	①/Eigen Vector
V_1	3.738	9.2923
V2	2.301	8.6492
V3	0.705	8.0957
V4	0.139	10.7175
V5	1.301	8.2651
V6	0.438	8.9402
V7	0.247	9.8142
V8	0.754	8.2962
λ_{max}-n		1.0088
CI		0.1441
RI		1.4000
CR		0.103
Consistency		Yes

3. Conclusions

This study conducted to investigate the influence of survey method on the safety culture assessment using AHP method. In general, the survey factors/questionnaires for measuring attributes of the safety culture have multidimensional and interrelation characteristic as well as strongly depend on surveyee's nature so that the quantitative analysis to the importance (weight) of survey factors/questionnaires is difficult.

In this study, the safety perception identified from the survey results was re-evaluated with an aim for the verification of the self-survey measurements performed by nuclear operating organization in years 2014 and 2015 respectively to identify the influences on the safety perception of management and worker from the survey results.

Evaluation results shows the difference between survey results and reexamination result using AHP because it may cause by either taking in account of weightage of surveyee's perception to the survey indicators (attributes) or not. In case of the survey results, all survey indicators (attributes) were taken as an equal importance while reexamination results were included weightage of each attributes during the comparative judgement by the AHP method.

In conclusion, the AHP method can be useful to obtain the importance (weight) of survey factors/questionnaires where surveyees are asked to select their preferred option from survey factors/questionnaires. Besides, this approach is also adequate tool to identify the preferred attributes in survey questionnaires among a set of safety culture attributes with an aim to enhancement strategies and decisions of safety culture in nuclear power plants. Furthermore, this study also proposes AHP approach for deriving the validity and vulnerability of safety culture measurement taking into account of the different individual perception of surveyees to the safety culture attributes.

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